ANALYSIS

29(112), March 1, 2015

ISSN 2278–5469 EISSN 2278–5450

Discovery

Thermal performance of compound parabolic solar air heater

Patel DK [1☼], Brahmbhatt PK[2]

1.Associate professor, Government Engineering College, Patan, India, Email: - dkpatel09@gmail.com
2.Associate Professor, Government Engineering College, Modasa, India, Email: - pragneshbrahmbhatt@gmail.com

Publication History
Received: 09 January 2015
Accepted: 14 February 2015
Published: 1 March 2015

Citation
Patel DK, Brahmbhatt PK. Thermal performance of compound parabolic solar air heater. *Discovery*, 2015, 29(112), 138-143

ABSTRACT

The thermal performance of a compound parabolic solar air heater for a single pass was investigated experimentally. V-shaped corrugated absorber plate was used as a absorber plate to increase the heat exchange. A low cost solar air heater with cpc having an aperture area of 1.2m^2 and a flat absorber with concentration ratio two was fabricated and experimentally tested at Patan, North Gujarat (23.4^{O}N, 72^{O}E) and operating performances determined. The effect of mass flow rate of air on the outlet temperature, thermal efficiency was studied. Experiments were performed for two air mass flow rates of 0.012 and 0.016 kg s^{-1}. the presented results can be considered important for the design and the operation of solar air heaters used for drying agricultural products, space heating and, industrial purposes.

Keywords: Solar Air Heater, Reflectors, Auto LISP, Compound parabolic concentrator (CPC).

1. INTRODUCTION

A solar heater is a simple and effective device to harness solar radiation for drying agricultural products, space heating and other purposes. Also solar air heaters are utilized for heating buildings with auxiliary heaters to save energy in winter-time. Conventional type solar air heaters mainly consist of glazing with an absorber plate or glazing with a duct of two parallel plates forming a passage for air flow with top plate acting as an

absorber. This arrangement is insulated thermally from back and the sides. Solar radiation, in the form of solar thermal energy, is an alternative source of energy for drying especially to dry fruits, vegetables, agricultural grains and other kinds of material, as wood, etc. This procedure is especially applicable in the so-called "sunny belt" worldwide, i.e. in regions where the intensity of solar radiation is high and sunshine duration long. It is estimated that in developing countries there exist significant post harvest losses of agricultural products, due to lack of other preservation means, that can be saved by using solar dryers. Drying by solar energy is a rather economical procedure for agricultural products, especially for medium to small amounts of products, to preserve excess of production. Our study seeks to increase the thermal efficiency of solar air heater, by using a single pass compound parabolic solar air heater. Compound parabolic concentrator with concentration ratio two. Compound parabolic concentrator (CPC) is a non-imaging type concentrating solar collector where the incident rays, after reflection from the reflector, are not focused at a point or line but are simply collected on absorber (receiver) surface. The concentration ratio C, which is defined as the ratio of aperture area to absorber area is generally 2 to 10. CPC achieves the ideal concentration($C=1/\sin\theta_c$). It is generally oriented in E-W direction. It does not need a continuous tracking of the sun but it necessitates only a few tilt adjustments per year. A part of diffuse radiation is also accepted. CPC is much popular for the applications where medium temperature range is required. The CPC is the only type of concentrator that reaches the theoretical maximum concentration. It consists of parabolic reflectors that funnel the radiation from the aperture to the receiver. Winston (1970) proved by using the principle of phase space conservation that the highest possible concentration achievable is $1/\sin\theta_a$ for 2-D CPC collector. CPC can achieve this highest concentration, while the other concentrators fall short in achieving this limit. This limit plays the same role for concentrators as Carnot efficiency plays for heat engines. Eames and Norton (1995) introduced baffles in the cavity of CPC and performed the theoretical and experimental investigation into modifications in optical and thermal performance due to introduction of baffle.

The introduction of baffle into the collector cavity reduces total fluid movement and thus convective heat transfer from absorber to cover and reflector is reduced. The total collector efficiency is increased.. Tchinda (2008) quantified the heat transfer within compound parabolic concentrating solar energy collectors with a flat one-sided absorber. Gang,Jing and Jie (2010) analysed and designed the innovative configuration of low temperature solar thermal electric generation with regenerative Organic Rankine Cycle mainly consisting of small concentration ratio compound parabolic concentrators(CPC). Nkwetta and Smyth (2012) transferred Computer generated coordinates for the full and truncated CPC solar collectors to AutoCAD® formats to draw the profiles in a 'dxf' format enabling and used in construction of the reflector support and profiles. Murray and Nelson used AutoCAD® to investigate the properties of a tubular reactor in a solar furnace and to design a parabolic. Khonkar and Sayigh(1994) used AutoCAD® as one of the technique was adopted to investigate the location of the hot spots on the absorber to achieve an accurate ray trace and analyse the phenomena of the rays inside the CPC for different incident angle. Khonkar and Sayigh(1995) used a spreadsheet, EXCEL® by Microsoft® for calculating the profile and the absorber of the CPC solar collector with tubular receiver.

2. GEOMETRICAL CONSTRUCTION OF CPC PROFILE

Auto LISP is a powerful programming language that quickly create own commands, routines. It is a programming language that can greatly enhance productivity by automating often-used or repetitive tasks. This feature-rich software is used in AutoCAD® to specify points, do calculations and speed up repetitive tasks using macros. For using Auto LISP program in AutoCAD®, Auto LISP file can be load from within Visual LISP or from within AutoCAD®. AutoCAD® offers lsp files which can be used for Auto LISP routings as acad.lsp. Auto LISP program is developed for geometrical profile generation of CPC from polar coordinate equations and file save as cpc.lsp. Fig. 1 shows the computer generated Profile of CPC by adding two variables half acceptance angle θa and aperture length L2 in loaded cpc.lsp file of AutoCAD®

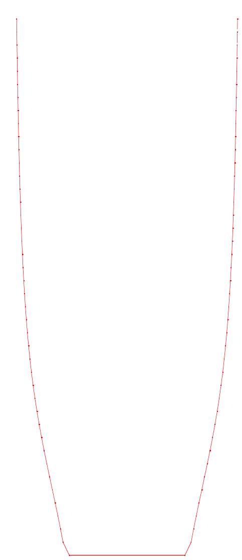

Figure 1 Geometric Profile of CPC (θ_a =30°, L2=60)

3. FABRICATION METHODOLOGY

D.K.Patel and P.K.Brahmbhatt (2014) designed and manufactured Compound parabolic solar air collector. The

factors which affect the performance of a solar collector include (i) the environmental factors (ambient temperature, solar radiation characteristics, latitude, altitude of location, wind speed.etc.) and (ii) the design variables (dimensions, material and thermal characteristics). The effect of the environmental factors are external and may not be easily altered for improved performance, thus only design variables are left as the only ones that may be considered for optimal collector performance. Auto LISP generated profile of CPC with acceptance half-angle 30˚and aperture width 60cm for the full and truncated solar air collector was printed to scale as printing templates and used in the construction of the reflector support and profile. The printed 'CPC profile generated by Auto LISP' design templates was then glued to the wooden supporting plates, which was pre-cut with measuring dimensions of(30x60x80cm), for the full profile as shown in fig.1.

Figure 2 Picture to show the prototype of CPC Solar Air Collector

The respective profiles were cut out using an saw and assembled in the laboratory. This technique gave an accurate profile and structure supports. and a rigid exo-skeleton framework supported the reflective panels of the collector. Anodized aluminium with a specular reflectance of approximately 80% is rolled as per Wooden templates profile for reflector .The collector assembly was placed in a location where there was access to sunlight and throughout the experiment, the collector was kept with its absorber aligned east-west with the tilt angle being the latitude of the place (23.4^{O}) towards south so as to maximize useful solar energy. Air was used as the heat transfer fluid. One collector panel with CPC truncated of the full size within the acceptance half angle of 30˚is fabricated. The collector has a total aperture area of 1.2 m^2 and a flat plat absorber area of 0.48m^2. This collector has overall dimensions of 0.8m height, 0.6m aperture width, 0.3m receiver width and 1.6m length the receiving surface which is black GI V-shaped corrugated absorber plate for improving the value of the heat transfer coefficient between the absorber plate and the air thus result in a higher efficiency forms the upper side of a rectangular airflow duct of depth 0.15m made of GI sheet 0.5 mm thick. The bottom of the duct is insulated with glass wool 50mm thick as shown in fig.2 [5-7]. Some of the factors to be considered in designing the parabolic structure ware that it was not distort significantly due to its own weight and able to withstand wind loads.

4. EXPERIMENTAL METHODOLOGY

The performance test of the prototype was carried out with glazing and thermal insulation including rectangular airflow duct, and total weather station at the Patan, North Gujarat (23.4^{O}N, 72^{O}E). In the experiment we measured the readings of global radiation H_t, absorber temperature T_r, reflector temperature T_m, cover temperature T_a, air inlet temperature T_i, air outlet temperature T_o and ambient temperature T_b, was taken for two mass flow rates m (0.012 kg/s and 0.016 kg/s) from 8 a.m. to 5p.m. at the interval of 1 hour in the month May 2014.In this study The absorber was made of galvanized iron sheet with black chrome selective coating and thickness of plate was 0.5mm. The cover window type, the Plexiglass of 3mm thickness, was used as glazing. Thermocouples were positioned evenly, on the top surface of the absorber plates along the direction of flow at identical positions for measuring inlet and outlet air temperatures. The output from thermocouples was recorded in degrees Celsius by using a digital thermocouple thermometer ADI111 measurement range -50 to 1300 ˚C; resolution 1˚C,accuracy,±2.2˚C. as digital thermometer measured the ambient temperature with sensor in display LCD placed in a special container behind the collectors' body. The total solar radiation incident on the surface of the collector was measured with a total weather station Pyranometer.

Fig.3 shows the hourly variations of the measured solar radiation of different conditions of the days with flat plate absorber plate, corresponding months such as May. The highest daily solar radiation is obtained as 965 and 918 W/m^{2}at solar air collector. It increases during the morning to some peak value and starts to decrease in the afternoon for all the days in which experiment was conducted as expected. Solar intensity is at their highest values at noon about 13: 00 as is expected. The solar intensity decreases as the time passes through the afternoon. The highest daily solar radiation is obtained as 965 and 918 W/m^{2}at solar air collector. It increases during the morning to some peak value and starts to decrease in the

afternoon for all the days in which experiment was conducted as expected.

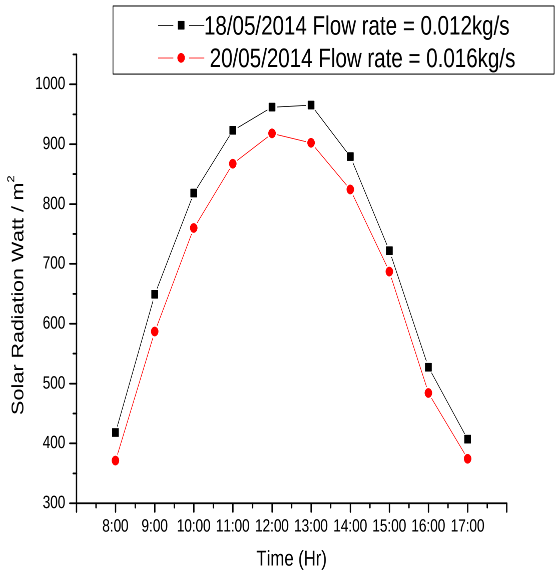

Figure 3 Hourly variation of solar irradiation, for months of May (2014)

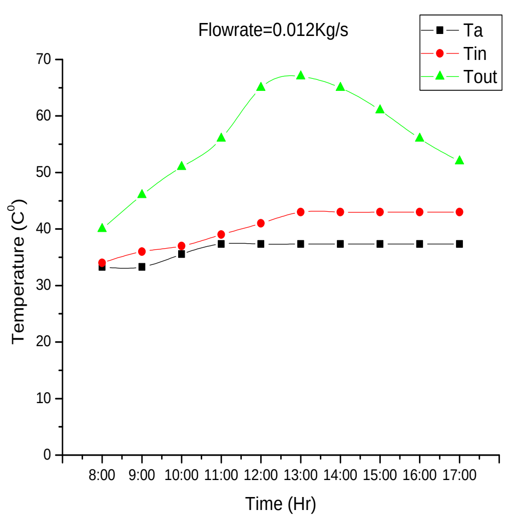

Figure 4 Temperature versus different standard local time during days for the flow rate at 0.012 Kg/s corresponding to the outlet, inlet, and ambient.

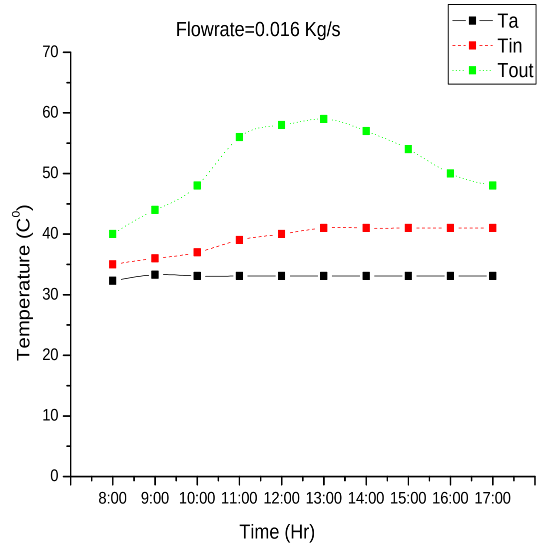

Figure 5 Temperature versus different standard local time during days for the flow rate at 0.016 Kg/s corresponding to the outlet, inlet, and ambient.

Fig. 4 & 5 show the variation of the ambient, outlet and inlet temperatures as a function of air mass flow rates and time during day. The temperature was measured experimentally, and it can be seen from graph that the curves of outlet temperature tend to decrease with increasing air mass flow rate. For a specific air mass flow rate at a constant ambient temperature, the outlet and inlet temperatures increase with increasing solar intensity. In general, the inlet temperature was found to be increasing exponentially from the morning for mass flow rates m =0.012 kg/s and 0.016 kg/s . In particular; Tin= 36˚C at 9:00h, for ambient temperature T_a=33.3˚C.The thermal efficiency of the prototype geometrically constructed CPC solar collector is presented in Figure 6. The thermal output Q_u [inW] of collector was determined by measuring (with type-k thermocouples) the temperature rise of air flowing through the collector, and multiplying it by heat capacity C and mass flow rate m

$$Q_u = mc(T_o - T_i) \quad (1)$$

The flow rate was measured by digital anemometer. The most general equation used for the calculation of solar collector efficiency, which can be expressed as the ratio of the heat stored into collector to the total heat amount incident onto the collector during the same time, refer to "(2)".

$$\eta = \frac{mc(T_o - T_i)}{H_t A_a} \quad (2)$$

Where c = specific heat of air = 1009 J/kg-K

A_a =aperture area = W×L2

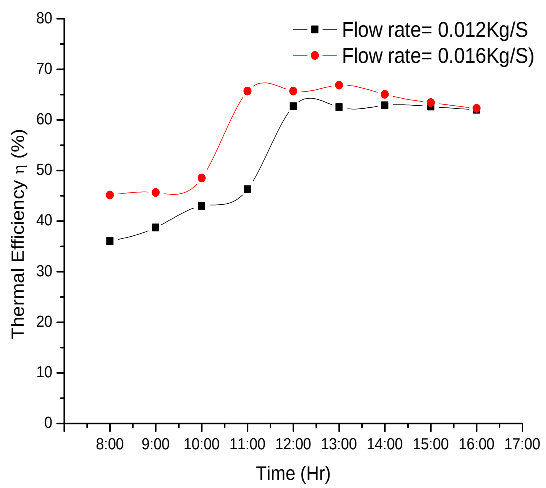

Figure 6 Collector efficiency with the local time

5. CONCLUSION

The present study aims to review designs and analyse a thermal efficiency of solar air heater. The efficiency of the solar air collectors depends significantly on the solar radiation, mass flow rate, and surface geometry of the collectors and with using v-shaped corrugated back absorber plate. The efficiency of the collector improves with increasing solar intensity at mass flow rate of 0.012 and 0.016 kg s^{-1}, due to enhanced heat transfer to the air flow. Optimum values of air mass flow rates are suggested to maximize the performance of the solar collector. The reason for the significant increase in efficiency from of 0.012 and 0.016 kg s^{-1} can be attributed to changes in flow condition from laminar to turbulent. It could also be seen that slope of the efficiency curves decreases, meaning decrease in loss coefficient, with increase in mass flow rates. CPC profile generated by Auto LISP is more accurate, error free and requires less time than drawn by hand, used for modeling of mcc and analysing raytrace for different incident angle. The prototype can be easily geometrically constructed and fabricated through Do-It-Yourself (DIY) using low cost material (GI). The air outlet temperature (66˚C) attained by CPC is higher than available in FPC even when the CPC is flat. The stationary low cost CPC solar air heater with the concentration ratio of 2 suns has been proposed for air heating with specific advantages of no need of continuous tracking, no utmost accuracy required in fabrication, acceptance of diffuse radiation, saving of material by truncation, low loss coefficient and low cost. It is still used for domestic up to small commercial size drying of crops, agricultural products and foodstuff, such as fruits, vegetables, aromatic herbs, wood, etc., contributing thus significantly to the economy of small agricultural communities and farms.

ACKNOWLEDGMENT

This work was done within the framework of the MAMATA ENERGY, Ahmedabad. Financial support from the TEQIP-II is also acknowledged. The authors would like to thank Prof. K.B.Judal for helpful counseling.

REFERENCE

1. Winston R. (1974) Principles of solar concentrators of a novel design. *Solar Energy*16, 89-95.
2. Rene Tchinda (2008) Thermal behavior of solar air heater with compound parabolic concentrator, Energy *conversion and Management* 49(2008) 529-540.
3. R.S.Gill, Sukhmeet Singh, Parm Pal Singh (2012) Low cost solar air heater, Energy conversion and Management 57(2012) 131-142. Science Direct, Elsevier.
4. Pei Gang,Li Jing, Ji Jie (2010) Analysis of low temperature solar thermal electric generation using regenerative Organic rankine Cycle, *Applied Thermal Engineering* 30 (2010) 998-1004. Dan Nchelatebe Nkwetta, Mervyns
5. Smyth (2012) performance analysis and comparison of concentrated evacuated tube heat pipe solar collectors, *Applied Energy* 98 (2012) 22-32.
6. Khonkar and Sayigh (1994) Raytrace for Compound parabolic concentrator, *Renewable Energy,* Vol-5,Part I ,Pages 376-383
7. Khonkar and Sayigh (1995) Optimization of the Tubular absorber using a Compound parabolic concentrator, *Renewable Energy*, Vol-6,No-1,Pages 17-21.
8. Winston, R., Minaco, J.C., Benitez, P.,Shatz, N., & Bortz, J.C.(2005). Nonimaging optics, *Elsevier Academic Press*, London, UK.
9. Rene T chinda .Thermal behavior of solar air heater with compound parabolic concentrator. Energy conversion and Management 49(2008) 529-540. Science Direct, Elsevier.
10. Pramuang s, Excell RHB. Transient test of a solar air heater with a compound parabolic concentrator Renewable Energy 2005; 30:715– 728. Science Direct Elsevier.
11. D.K.Patel and P.K.Brahmbhatt (2014)'Compound Parabolic Solar Concentrator with AutoLISP' Proc. Ist International Conference on MEET, Bhopal. pp 941-947.
12. D.K.Patel and P.K.Brahmbhatt (2014)'Computer Aided Design and Manufacture of Compound Parabolic Solar Air Collector'' Proc. International Conference on Recent Trends

in Engineering and Technology, Published by Elsevier, pp, 134-136.

13. Ellen Finkelstein (2006) AutoCAD® and AutoCAD LT® Bible, *Wiley Publishing Inc*. Indianapolis, Indiana
14. SANTO GRILLO (1984) A New model of stationary concentrator formed with multiple channels having reflecting walls, Solar *Energy* Vol.32 no.4, pp. 443-451.